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Peter, J.; Kühne, R.; Barco, A.; de Jong, C.; van Straten, C.L.

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Jochen Peter, Rinaldo Kühne, Alex Barco, Chiara de Jong, & Caroline L. van Straten

Amsterdam School of Communication Research

University of Amsterdam

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Abstract

Social robots and the Internet of Toys present key technologies in children's future life. Based on Winfield (2012), we conceptualize the relationship between social robots and smart/connected toys with six characteristics: interactivity, energy, sensors, software-control, movement, and embodiment. These characteristics, in turn, help to classify social robots and smart/connected toys along three dimensions (i.e., horizontal, vertical, and spatial integration), which suggests that social robots and smart/connected toys differ gradually rather than categorically. We identify three common theoretical (absence or heterogeneity of theory, lacking developmental perspective, insufficient attention to intercultural differences) and three methodological issues (lack of standardized measures, study design issues, dominance of cross-sectional studies) that research on both social robots and the Internet of Toys needs to address.

Keywords: child-robot interaction; human-robot interaction; human-machine interaction; artificial intelligence; childhood

Asking Today the Crucial Questions of Tomorrow: Social Robots and the Internet of Toys

The past two decades have seen dramatic technological changes (e.g., Eberl, 2016; Ross, 2016; Van Bergen, 2016; for a summary, see: Peter, 2017a, 2017b): Computers have become ever more powerful and computing has turned into a mobile activity, at least where stable mobile networks are available. In addition, digital information has become easily available in large information networks, notably the Internet. Much computing to date takes place in the cloud, which has disassociated information and software on the one hand from hardware devices on the other hand. At the same time, the costs of many technical devices, especially sensors, cameras, and audio devices, have dropped sharply. Finally, insights from machine learning keep on advancing artificial intelligence (AI) and, as a consequence, the increasingly autonomous functioning of hitherto heteronomously operated devices (Thrun, 2004).

The technological changes of the past twenty years come together in current social robots, which are often predicted to make a major impact in the future (Barnatt, 2015; Ross, 2016). Robots have been around more than 50 years, but mainly as industrial and service robots (Thrun, 2004). These types of robots are typically designed to do work that is too dangerous or repetitive for human beings (e.g., Winfield, 2012). Although industrial and service robots usually operate autonomously in a particular environment, they are unable to engage with human beings in even the most basic way (industrial robots) or beyond the very restricted service task they are programmed to do (service robots) (Thrun, 2004). Social robots, in contrast, are designed to interact in a meaningful way with human beings and act and react autonomously in a variety of social situations (e.g., Breazeal, 2003; Dautenhahn, 2007; Fong, Nourbakhsh, & Dautenhahn, 2003; Lee, Peng, Jin, & Yan, 2006; Zhao, 2006).

To date, social robots have been used primarily in the care for the elderly and as a device for children with an autism-spectrum disorder, that is, developmentally atypical children (e.g., Cabibihan, Javed, Ang, & Aljunied, 2013; De Graaf, Ben Allouch, & Klamer, 2015). However, social robots may also be relevant to developmentally typical children, notably when it comes to the Internet of Toys (Wang, Kuo, King, & Chang, 2010). Drawing on Holloway and Green's (2016) work, the Internet of Toys has been defined, as "a set of software-enabled toys that: 1) are connected to online platforms through WiFi and Bluetooth, but also, potentially, to other toys; 2) are equipped with sensors; and 3) relate one-on-one to children" (Mascheroni & Holloway, 2017, p. 5). The Internet of Toys is itself part of the Internet of Things, which is "a network of entities that are connected through any form of sensor, enabling these entities, which we term as Internet-connected constituents, to be located, identified, and even operated upon" (Ng & Wakenshaw, 2017, p. 4, emphasis removed from original).

Although social robots have been emphasized as an important part of the Internet of Toys (e.g., Future of Privacy Forum & Family Online Safety Institute, 2016; Mascheroni & Holloway, 2017; Peter, 2017b), it is still unclear how social robots and the Internet of Toys relate to each other at a conceptual level. The above definitions of the Internet of Toys and the Internet of Things highlight, for example, networked connectivity and sensor technology. These characteristics also appear in definitions of, and discussions about, (social) robots (e.g., Van Bergen, 2016; Winfield, 2012). Robots, however, include many more technological features (Winfield, 2012) and we do not know to what extent these features are relevant to the Internet of Toys. The first goal of this chapter is to address this issue.

As research on social robots and the Internet of Toys responds to recent fast-paced technological changes, both fields are still in a nascent state. Moreover, with their inherently interdisciplinary character, both fields attract attention from a diverse range of disciplines, from the engineering sciences and robotics, to law and philosophy, to the humanities and social sciences (for robots, e.g., Baxter, Kennedy, Senft, Lemaignan, & Belpaeme, 2016). As a result, we face – even when researchers ask the same questions – a diverging focus and emphasis in theoretical and conceptual frameworks as well as in methodological approaches and standards, certainly in research on social robots (e.g., De Jong, Peter, Kühne, & Barco, 2018; Eyssel, 2017; Van Straten, Peter, & Kühne, 2018). Against this background, it is important that, already today, we are asking crucial questions about theoretical and methodological issues that are common to research on both social robots and the Internet of Toys. The second goal of this chapter is to identify and discuss theoretical and methodological problems that need to be solved to ensure progress in the two fields.

Social Robots, Smart Toys, and Connected Toys

Although the literature on the Internet of Toys typically points out that toys with mechanical and electronic features have a long history (e.g., Future of Privacy Forum & Family Online Safety Institute, 2016; Wang et al., 2010), it also emphasizes that several current toys have new crucial features: They are unprecedentedly "smart" and they are "connected" to the Internet (Chaudron et al., 2017; Future of Privacy Forum & Family Online Safety Institute, 2016; Mascheroni & Holloway, 2017). Given the prominence of smart and connected toys in the literature on the Internet of Toys, in what follows we refer to these two rather than to the Internet of Toys, which also facilitates the comparison with social robots.

Smart toys are usually defined as toys that "contain embedded electronic features such that they can adapt to the actions of the user […] [and] process more information from a greater variety of sensors. This may include the use of microphones or speech recognition, cameras for detection of patterns and visual cues, accelerometers, proximity sensors, gyroscopes, compasses, radio transmitters, or Bluetooth for communicating between various parts to [sic] the same toy" (Future of Privacy Forum & Family Online Safety Institute, 2016,

p. 2). Smart toys, however, are only part of the Internet of Toys if they are *connected* toys (Future of Privacy Forum & Family Online Safety Institute, 2016). "Connected toys […] incorporate Internet technologies that respond to and interact with children. They are sometimes equipped with speech recognition and activation and appear to react to the words of the user. They may also be controlled remotely across network infrastructure, for example via smartphones or tablets connected to the same network. These toys often use sophisticated sensor-based technologies to collect information from children and cloud-based platforms to process this information through real-time interactions. This cloud-based processing relies on sophisticated algorithms that can simulate human intelligence (AI) and deliver more personalised or individualised responses to children" (Mascheroni & Holloway, 2017, p. 5; see also Future of Privacy Forum & Family Online Safety Institute, 2016).

Defining Features of Smart Toys, Connected Toys, and Social Robots

A smart toy does not have to be connected to the Internet and a connected toy does not have to be smart (Future of Privacy Forum & Family Online Safety Institute, 2016; Mascheroni & Holloway, 2017). Still, at a conceptual level, the above definitions of smart and connected toys include at least four common features, which Winfield (2012) has identified as defining functions of robots, as will be elaborated upon below. First, both smart and connected toys are electronic devices that need *energy* (from batteries or mains power). Second, both smart and connected toys tend to rely on one or more types of *sensors* (e.g., visual, audio, haptic) for input from their human and non-human environment. For smart toys, this input comes from their own, immediate environment and is unique to the particular toy. For connected toys, this input may in addition come from another, remote environment (e.g., in the form of information stored in the cloud). This input is thus unspecific to the particular toy. Third, smart and connected toys alike are *software-controlled,* which largely determines their 'intelligence.' Whereas, in smart toys, the software is embedded, it may be controlled remotely in connected toys. Fourth, smart and connected toys both *interact* with children; they thus not only process input from their human environment, but also respond to it.

The definition of smart toys includes, at least implicitly, two more conceptually important features that also merge with functions of robots as outlined by Winfield (2012). The emphasis on accelerometers, gyroscopes, and compasses suggests that smart toys may be able, or are intended, to *move* in the physical world. In addition, the above definition of smart toys highlights that smart toys have tangible material components. This points to the possibility that such toys may be embodied. *Embodiment* can be defined as “having a body in the physical world” (Looije, van der Zalm, Neerincx, & Beun, 2012, p. 719) (for an elaborate definition see, Fong et al., 2003).

As mentioned above, the four features of smart and connected toys – energy, sensors, software control, and interactivity – as well as the two potential additional features of smart toys – movement and embodiment – overlap with what Winfield (2012) considers characteristic functions of robots. According to Winfield (2012, p. 4), “[s]ome of [the] five functions – sensing, signalling, moving, intelligence, and energy, integrated into a body – are present in all robots.” As Winfield (2012, pp. 4–7) elaborates for the various functions, sensing includes vision, hearing, touch, relative and absolute orientation, location sensing, as well as short-range sensing (e.g., through infrared sensors) and long-range sensing (e.g., through laser sensors). Signalling refers to sounds, facial and body gestures, lights, and radio. Moving comprises motor-based wheeled, legged, or flying movements. A robot’s intelligence depends on its hardware – the microprocessor(s) – and its software, without which a robot is unable to operate because they are needed to process the sensors’ input. The energy of a robot comes from mains power, batteries, solar panels, or fuel cells (for an overview of the five functions, see Winfield, 2012, particularly Table 1, p. 7). The type and shape of a robot’s body are related to its morphology (Winfield, 2012): It can be anthropomorphic and have human-like features; it can be zoomorphic and have animal-like features; it can be caricatured and look like animation figures; or it can be functional and have machine-like features (Fong et al., 2003). Anthropomorphic and functional robots currently dominate research (Riek, 2012).

Winfield's (2012) definition of robot functions refers to robots in general. As a result, interactivity with humans – in the sense of a meaningful exchange of symbols – is not explicitly included in his definition. Winfield does emphasize the signalling function of robots, broadly speaking the ability of robots to communicate in a textual/verbal or nontextual/nonverbal fashion. However, only when a robot is able to both act upon and react meaningfully to its (human) environment does it become interactive. Next to their capacity to adhere to the rules that belong to a particular social role ("Social robot," n.d.), the ability of robots to both send and receive signals, or more specifically symbols, in a variety of interactions with human beings is essential for their social character (e.g., Breazeal, 2003; Dautenhahn, 2007; Fong et al., 2003; Zhao, 2006). The features of social robots (Winfield, 2012) thus resemble those of smart toys: Both (1) are interactive; (2) need energy to function; (3) use sensors to sense their social environment; (4) are controlled by software; (5) can move; and (6) are embodied. Connected toys differ from smart toys because their input may also come from elsewhere than their immediate environments and, notably, because their software can be remotely controlled. Connected toys differ from social robots because, in contrast to social robots, connected toys typically need to be connected to a network to function.

Horizontal, Vertical, and Spatial Integration

Against this background, the question arises what distinguishes social robots from smart toys. In one of the first papers on the Internet of Toys, Wang et al. (2010, p. 265) have classified smart toys (in the form of ePets) amongst other things along their level of integration, that is the extent to which smart toys “integrate more sensors, actuators [i.e., devices that control movements], mechanical parts, and computing resources […][to] make more sophisticated movements and expressions. They are closer to robots.” In this classification, smart toys and social robots thus differ gradually rather than categorically. However, Wang et al. (2010) do not provide a theoretical rationale for the characteristics in which the integration of smart toys and social robots differ. Moreover, they do not define these characteristics explicitly.

To distinguish more precisely between smart toys and robots and, at the same time, include the connectivity of connected toys as a dimension in its own right, it may be useful to rely on the aforementioned six features of social robots and to differentiate between vertical, horizontal, and spatial integration. The terms are typically used in economics and related fields and refer to the integration between companies (Colangelo, 1995) and regions (Van Oort, Burger, & Raspe, 2010). We use them here to explicate and extend Wang et al.’s (2010) notion of a device’s integration. The notion that technological devices can be differentiated along the number and complexity of their characteristics (which we explicate below) is inspired, for example, by the idea that media can be distinguished by their “richness” (through, for instance, immediate feedback and more modalities; e.g., Daft & Lengel, 1986).

Horizontal integration overlaps with Wang et al.’s (2010) definition of integration, but relies on the six features of social robots identified above. It captures *how many* of the six features are present in a given device, where each feature is seen as a binary (present – absent) variable. The more of the six features a device has, the more horizontally integrated it is. It is, however, hard to think of smart toys and social robots that do not feature interactivity, energy, sensors, and software-control. Consequently, movement and embodiment play a crucial role in distinguishing smart toys and social robots in terms of their horizontal integration.

The concept of *vertical* integration goes beyond Wang et al.'s (2010) definition of integration. It refers to the *degree* to which each of the six features of social robots is present in a given device. Interactivity, energy, sensors, software-control, movement, and embodiment are thus each seen as a continuum. Consequently, smart toys and social robots can be distinguished by how interactive they are; how independent they are from energy supply (e.g., through batteries); how many different sensors they have (e.g., vision, hearing, touch, location); how powerful their software control is (and thus their 'intelligence'); how smoothly and robustly they can move in the physical world; and how embodied they are (e.g., from no body to merely visible to tangible body). By and large, current social robots will differ much more from smart toys in their vertical than in their horizontal integration: Not only do social robots have the highest level of embodiment as well as multiple sensors and actuators (for movement), but they also feature high levels of interactivity and advanced software control.

Finally, the concept of *spatial* integration theoretically explicates Wang et al.'s (2010) idea of the Internet of Toys: Spatial integration explicitly captures the connectivity of toys and social robots, thereby cutting through vertical and horizontal integration. High spatial integration means that a device needs to be continuously connected to function properly, whereas low spatial integration means that a device can incidentally be connected for (better) functioning (e.g., by downloading software updates). As connectivity plays a major role currently in the sensorial input and software control of connected toys, it is possible that it affects, in the future, their movements and interactivity.

It is important to note, however, that spatial integration does not have to go hand in hand with horizontal and vertical integration (Future of Privacy Forum & Family Online

Safety Institute, 2016): A connected toy may be high in spatial integration, but lower in horizontal and/or vertical integration. Conversely, devices such as social robots may be high in horizontal and vertical integration, but low in spatial integration. For example, as a connected toy, the digital, smart-phone-based toothbrush game/toy Grush (Grush) is higher in spatial integration than the social robot Nao (Softbank), as Grush, unlike Nao, needs to be connected to a network to function. Nao, in contrast, is higher in horizontal and vertical integration than Grush: Nao features energy, interactivity, motion sensors, software-control, embodiment, and movement in the physical world, and all of them to an advanced degree. Grush lacks, in particular, both embodiment and movement in the physical world. The remaining four characteristics are less advanced in Grush than in Nao.

In sum, the relationship between the Internet of Toys – here: smart toys and connected toys – on the one hand and social robots on the other can be conceptualized along six characteristics: interactivity, energy, sensors, software-control, movement, and embodiment (Winfield, 2012). Together with connectivity, these six characteristics help to classify smart toys, connected toys, and social robots along three dimensions: horizontal, vertical, and spatial integration. It is inherent to this classification that smart toys, connected toys, and social robots differ gradually rather than categorically. As a result, it is conceivable that research on smart and connected toys as well as research on social robots may face similar conceptual and methodological issues.

Conceptual and Methodological Issues

Research on both social robots and the Internet of Toys covers emerging fields. Still, research on social robots is currently more elaborate than research on the Internet of Toys (as of June 2018, a search for studies in the Web of Science elicits two hits for “Internet of Toys” and 311 on “social robots”). For the identification of conceptual and methodological issues, we therefore mainly rely on research on social robots.

Conceptual Issues

Broadly speaking, research on social robots can be divided into research on robot technology and research on human-robot interaction (HRI), which is most relevant to this chapter. In research on HRI in general and on child-robot interaction (CRI) in particular, at least three conceptual issues currently deserve attention. These issues are the absence or heterogeneity of theoretical frameworks; the lacking focus on developmental differences between (child) robot users; and insufficient attention to intercultural differences in how humans deal with robots.

Absence or heterogeneity of theoretical frameworks. Novel research fields typically lack unifying conceptual and theoretical frameworks; after all, fields usually build and test theories only when they mature (Kuhn, 1970). Social robotics, however, is an interdisciplinary field (Baxter et al., 2016) that can, in principle, draw on a variety of theoretical frameworks established in the various disciplines. In this context, it is striking that, in a recent evaluation of research on HRI, Eyssel (2017, p. 365) concluded: “Browsing conference proceedings and even journal publications in the field, it becomes clear that many a paper lacks an actual theory section. While an introduction into the literature is commonly provided, one sometimes pauses to wonder what the just read ‘Related Work’ section would tell us about the study that has actually been conducted?” The need for more theory-driven research is echoed by other scholars (Dautenhahn, 2007; De Jong et al., 2018; Krämer, Eimler, von der Pütten, & Payr, 2011). In a recent review of what shapes children’s acceptance of social robots De Jong et al. (2018) more specifically pointed out that many of the studies on the determinants of children’s acceptance of social robots remain theoretically somewhat ad-hoc and are consequently difficult to compare. The authors, therefore, call explicitly for an overarching theoretical framework that can guide research on children’s acceptance of social robots (see also Van Straten et al., 2018).

Even if studies are based on established theories, the approaches remain heterogeneous and scattered. For example, in a review of HRI Broadbent (2017) identified at least seven conceptual and theoretical frameworks used in research: evolutionary theory, realism inconsistency, psychoanalysis, media equation, anthropomorphism, perceptions of mind, and emotional attachment. A cursory look at recent publications on HRI and CRI elicits several more approaches, for instance uncertainty reduction theory and expectancy violation theory (Edwards, Edwards, Spence, & Westerman, 2016; Spence, Westerman, Edwards, & Edwards, 2014), self-determination theory (Looije, Neerincx, Peters, & Henkemans, 2016), theory of planned behaviour (De Graaf, Ben Allouch, & van Dijk, 2017), or attachment theory (Dziergwa, Kaczmarek, Kaczmarek, Kędzierski, & Wadas-Szydłowska, 2018) (for references to the origins of the theories, see the cited publications). The variety of the used theoretical frameworks shows the dynamic character of the field but also calls for a more integrative, cumulative, and overarching treatment of theories (Eyssel, 2017). Compared to research on HRI and CRI, research on the Internet of Toys is still in a *statu nascendi*. Given the similarities between the two fields, however, it is important that research on the Internet of Toys commit to theory formation and integration right from the start. The distinction between horizontal, vertical, and spatial integration of devices may be a first tentative step into this direction.

Lacking focus on developmental differences. Research on the Internet of Toys and on the subfield of CRI in HRI inherently centres on children and adolescents. However, between childhood and adolescence – as well as within childhood and adolescence – enormous developmental differences occur. These developmental differences encompass cognitive, emotional, social, physical, and psychological changes (e.g., Lightfoot, Cole, & Cole, 2013; Steinberg, 2008). From what we know about how young people select and use media (e.g., Valkenburg & Taylor Piotrowski, 2017), it is likely that developmental differences also affect how young people approach smart toys and social robots; how they interact with them; and which consequences this has(e.g., Beran, Ramirez-Serrano, Kuzyk, Fior, & Nugent, 2011; Kahn et al., 2012). Simply put, a smart toy that attracts a four-year old may be boring for a seven-year old. A talk with a social robot may lead a seven-year old to believe s/he has made a friend, but may seem ridiculous to a 12-year old. And understanding the technological components of a social robot may overwhelm a 12-year old, but may very well be possible for a 16-year old (e.g., Beran et al., 2011) .

Several studies on social robots have dealt with age differences between children, using a theoretically driven developmental perspective (e.g., Beran et al., 2011; Kahn et al., 2012). However, much research seems to focus on particular age groups of children based on pragmatic rather than developmental considerations (e.g., De Jong et al., 2018). To be clear, in several cases it may be useless, or trivial, to compare different developmental groups when interacting with a social robot. For example, comparing four- and eight-year-olds in how particular robot features affect learning mathematical operations from a social robot seems futile because four-year-olds are cognitively not ready for such a task. Similarly, some smart or connected toys may be targeted at particular age groups; comparisons between developmental groups may thus make little sense. In contrast, a developmentally oriented approach to differences between young people’s interaction with social robots and smart or connected toys may be appropriate when these devices are studied from a conceptual perspective. For instance, it is unclear to what extent different degrees of horizontal, vertical, and spatial integration attract, or repel, different developmental groups and why this may be the case (De Jong et al., 2018). Similarly, many of the risks of connected toys for the privacy and security of young people (e.g., Holloway & Green, 2016) may be better understood on the basis of developmental theory.

Insufficient attention to intercultural differences. While several studies in HRI have dealt with intercultural differences (e.g., Bartneck, Suzuki, Kanda, & Nomura, 2007; Li, Rau, & Li, 2010), cross-cultural comparative studies are still rather exceptional in research on CRI (e.g., Kanngiesser et al., 2015; Shahid, Krahmer, & Swerts, 2014). Our knowledge about CRI is therefore limited to the specificities of the country where a particular study was done, which are typically rich Western(ized) or Asian countries. As a result, we know little about how children in poorer and non-Western(ized) countries deal with social robots. It is, however, conceivable that a country's wealth, technological infrastructure, and legal regulations of technology affect whether and how children (are able to) encounter advanced technologies, such as smart toys and social robots, and which consequences this has. As others have already pointed out (e.g., Li et al., 2010), more attention to intercultural differences is thus needed.

In this context, it is essential that the study of intercultural differences move beyond a crude comparison of countries (Przeworski & Teune, 1970). At a theoretical level, we learn little by establishing that, for example, children in a Western European country may approach a social robot with somewhat more hesitation than children in Japan do. Following long-standing requests in comparative research, we need to abandon describing differences between countries in favour of explaining these differences with theoretically meaningful concepts (Przeworski & Teune, 1970). As children's play and interaction with smart and connected toys, as well as with robots, oscillates not only between the private and the public, but also between the local and the global (Marsh, 2017), research on intercultural differences seems more timely than ever.

Methodological Issues

With research on HRI and CRI coming from so many different disciplines, it is not surprising that methodological approaches and standards differ across studies. Although the methodological diversity across disciplines may foster cross-fertilization, it may also impair the quality of studies and the comparability of the results. In line with Eyssel (2017), we therefore focus on three issues in research on CRI: the lack of standardized measures, issues in the design of studies, and the dominance of cross-sectional studies.

Lack of standardized, child-validated measures. The shortage of measures that have been standardized and validated for particular groups, for example children, is not genuine to research on HRI or CRI and has been observed also in other interdisciplinary fields (e.g., Peter & Valkenburg, 2016). Still, the use of non-standardized measures not only questions the validity of measurement, but also impedes the comparability of the findings. For example, a recent review of children's relationship formation with robots (Van Straten et al., 2018) concluded that key concepts, such as closeness with and trust in a robot, were sometimes operationalized in debatable ways. At the same time, observable behaviour, such as smiling, was used to capture different concepts. The lack of standardized measures was also noticed in a review of children's acceptance of robots (De Jong et al., 2018). The reviewed studies not only differed in conceptual definitions of robot acceptance, but also in their operational definitions of the concept, which eventually may contribute to the paucity of consistent patterns in current studies on children's acceptance of robots. The lack of standardized measures is particularly problematic in studies among children, who are the key user group of smart and connected toys. Ideally, measures are not only standardized, but also appropriate for research with children. If we use non-standardized measures without evidence of their validation among children, several of our results may be imprecise.

The current scarcity of standardized, child-validated measures in current research on CRI touches upon the more general issue of the quality of measurement. Eyssel (2017) has, therefore, called for more attention to physiological measures (e.g., reaction time, galvanic skin response, functional brain imagining) next to self-report measures, which may be plagued by cognitive and motivational biases (e.g., memory errors, social desirability tendencies in answering). Similarly, Bethel and Murphy (2010) have emphasized the need for the triangulation of measurement approaches in HRI research. While the advances in indirect, physiological measurement techniques are impressive, they may not be readily accessible to many researchers or inconvenient with children. In this context, observational measures may be a useful alternative, notably for studies that take place in children's natural habitat (e.g., Pellegrini, Symons, & Hoch, 2012), as it seems likely for research on smart and connected toys.

Issues in the design of studies. Whether a study opts for an exploratory, correlational, or experimental design depends on many considerations, ranging from the state-of-the-art in a field to research ethics to feasibility. Against this background, researchers may sometimes have to take suboptimal decisions about their research design, especially when dealing with children. However, it remains important that research questions or hypotheses that make a causal claim be investigated in an internally valid way. Accordingly, Bethel and Murphy (2010, p. 347) have noted that "there is a growing need for strong experimental designs and methods of evaluation" in HRI (see also, Eyssel, 2017). Still, the aforementioned review of the influence of robot features on closeness with, and trust in, robots found that about one third of the studies had a correlational design (Van Straten et al., 2018), a figure that also surfaced in another review on antecedents of children's acceptance of social robots (De Jong et al., 2018). This problems is exacerbated by the small number of participants in some studies and the pertinent lack of statistical power (e.g., Baxter et al., 2016; Bethel & Murphy, 2010; Eyssel, 2017). In line with others (e.g., Baxter et al., 2016; Bethel & Murphy, 2010; Eyssel, 2017), De Jong et al. (2018) for example warn of imprecise effect estimates or Type-2 errors because of underpowered studies. Despite the many complexities in research with children and their use of advanced technologies, such as connected toys and social robots, the issues of internal validity and statistical power deserve greater attention than they have hitherto received (see also van Straten et al., 2018).

Dominance of cross-sectional studies. As mentioned before, new research fields need time to develop, not only in terms of their theoretical frameworks but also in terms of their methodological approaches. In this context, it seems understandable that the vast majority of studies on CRI are cross-sectional rather than longitudinal: In line with previous findings (e.g., Baxter et al., 2016), two recent review studies reported that 70% of studies on children's relationship formation with robots (Van Straten et al., 2018) and more than 80% of studies on antecedents of children's acceptance of social robots (De Jong et al., 2018) were cross-sectional. However, apart from not telling us anything about children's long-term use of robots and its consequences, the dominance of cross-sectional studies may create another, potentially more troublesome problem. For children's use of social robots, several researchers have called for attention to novelty effects (e.g., Kanda, Hirano, Eaton, & Ishiguro, 2004; Leite, Martinho, & Paiva, 2013): Due to its novelty, a toy or device initially elicits children's interest and enthusiasm, but the interest wanes off quickly once children have repeatedly played with the toy or device.

Novelty effects seem to be particularly problematic in CRI, where children's high expectations in social robots may be disappointed quickly by robots' still unstable and limited performance (e.g., Belpaeme et al., 2013). For cross-sectional studies, the novelty effect may imply that much of what we know from these studies may be snapshots of CRI in initial interactions, but may not apply to long-term interactions. As a result, it is crucial that more longitudinal research be conducted, preferably over a relatively long period (see also, e.g., Baxter et al., 2016; De Jong et al., 2018; Leite et al., 2013; Van Straten et al., 2018). Moreover, it is paramount that we do not extrapolate from cross-sectional studies how children approach, experience, and appreciate social robots in general (e.g., De Jong et al., 2018). Finally, we also need to take the possibility of novelty effects seriously in studies on smart and connected toys. The design and engineering of market-ready smart and connected toys may try to avoid novelty effects, for example by increasing the horizontal, vertical, and spatial integration of the toys. Still, the question of how children's play with the toys changes over time – and with the play its consequences – needs more attention and appropriate integration in our research approaches.

Conclusion

With the fast-paced and far-reaching changes in children's technological environment, it is important that, already today, we identify and ask the questions that will matter tomorrow. Social robots and the Internet of Toys – (smart) toys connected to the Internet (Mascheroni & Holloway, 2017) – present two of these changes in children's technological environment. From a conceptual point of view, smart toys, connected toys, and social robots differ only gradually, but not categorically: Social robots are typically higher in horizontal and vertical integration than are smart or connected toys. Once connected to a network, both smart toys and social robots may resemble connected advanced toys. Differences in horizontal, vertical, and spatial integration may raise novel questions. For example, it may be worth studying at which levels of the three types of integration children find a device attractive and how this develops over time. Similarly, we need to know which levels of integration impair or facilitate children's attachment to a device – both to maximize the opportunities and to reduce the risks of children's interaction with the device. To study such questions rigorously, however, we need to tackle several theoretical and methodological issues, both in research on social robots and the Internet of Toys. More consistently applied theories, attention to developmental and intercultural differences, a commitment to standardized, child-appropriate measures, more internally valid designs, and a longitudinal perspective may greatly help to start preparing today for what matters tomorrow.

References

Barnatt, C. (2015). *The next big thing: From 3D printing to mining the moon*. ExplainingTheFuture.com.

Bartneck, C., Suzuki, T., Kanda, T., & Nomura, T. (2007). The influence of people's culture and prior experiences with Aibo on their attitude towards robots. *AI & Society*, *21*(1–2), 217–230. https://doi.org/10.1007/s00146-006-0052-7

Baxter, P., Kennedy, J., Senft, E., Lemaignan, S., & Belpaeme, T. (2016). From characterising three years of HRI to methodology and reporting recommendations. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 391–398). Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/HRI.2016.7451777

Belpaeme, T., Baxter, P., Greeff, J. de, Kennedy, J., Read, R., Looije, R., … Zelati, M. C. (2013). Child-robot interaction: Perspectives and challenges. In *ICSR 2013 (Volume 8239)* (pp. 452–459). https://doi.org/10.1007/978-3-319-02675-6_45

Beran, T. N., Ramirez-Serrano, A., Kuzyk, R., Fior, M., & Nugent, S. (2011). Understanding how children understand robots: Perceived animism in child–robot interaction. *International Journal of Human-Computer Studies*, *69*(7–8), 539–550. https://doi.org/10.1016/j.ijhcs.2011.04.003

Bethel, C. L., & Murphy, R. R. (2010). Review of human studies methods in HRI and recommendations. *International Journal of Social Robotics*, *2*(4), 347–359. https://doi.org/10.1007/s12369-010-0064-9

Breazeal, C. (2003). Toward sociable robots. *Robotics and Autonomous Systems*, *42*(3–4), 167–175. https://doi.org/10.1016/S0921-8890(02)00373-1

Broadbent, E. (2017). Interactions with robots: The truths we reveal about ourselves. *Annual*

Review of Psychology, *68*(1), 627–652. https://doi.org/10.1146/annurev-psych-010416-043958

Cabibihan, J.-J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International Journal of Social Robotics*, *5*(4), 593–618. https://doi.org/10.1007/s12369-013-0202-2

Chaudron, S., Di Gioia, R., Gemo, M., Holloway, D., Marsh, J., Mascheroni, G., … Yamada-Rice, D. (2017). *Kaleidoscope on the Internet of Toys: Safety, security, privacy and societal insights (EUR 28397)*. Luxembourg. https://doi.org/10.2788/05383

Colangelo, G. (1995). Vertical vs. horizontal integration: Pre-emptive merging. *The Journal of Industrial Economics*, *43*(3), 323–337. https://doi.org/10.2307/2950583

Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness, and structural design. *Management Science*, *32*(5), 554–571. https://doi.org/10.1287/mnsc.32.5.554

Dautenhahn, K. (2007). Socially intelligent robots: Dimensions of human-robot interaction. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *362*(1480), 679–704. https://doi.org/10.1098/rstb.2006.2004

De Graaf, M. M. A., Ben Allouch, S., & Klamer, T. (2015). Sharing a life with Harvey: Exploring the acceptance of and relationship-building with a social robot. *Computers in Human Behavior*, *43*, 1–14. https://doi.org/10.1016/j.chb.2014.10.030

De Graaf, M. M. A., Ben Allouch, S., & van Dijk, J. A. G. M. (2017). Why would I use this in my home? A model of domestic social robot acceptance. *Human-Computer Interaction*, 1–59. https://doi.org/10.1080/07370024.2017.1312406

De Jong, C., Peter, J., Kühne, R., & Barco Martelo, A. (2018). Children’s acceptance of social robots: A narrative review of the research 2000-2017. *Manuscript Submitted for Publication*.

Dziergwa, M., Kaczmarek, M., Kaczmarek, P., Kędzierski, J., & Wadas-Szydłowska, K. (2018). Long-term cohabitation with a social robot: A case study of the influence of human attachment patterns. *International Journal of Social Robotics, 10*(1), 163–176. https://doi.org/10.1007/s12369-017-0439-2

Eberl, U. (2016). *Smarte Maschinen. Wie künstliche Intelligenz unser Leben verändert [Smart machines. How artificial intelligence changes our lives].* Munich, Germany: Hanser.

Edwards, C., Edwards, A., Spence, P. R., & Westerman, D. (2016). Initial interaction expectations with robots: Testing the human-to-human interaction script. *Communication Studies*, *67*(2), 227–238. https://doi.org/10.1080/10510974.2015.1121899

Eyssel, F. (2017). An experimental psychological perspective on social robotics. *Robotics and Autonomous Systems*, *87*, 363–371. https://doi.org/10.1016/j.robot.2016.08.029

Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and Autonomous Systems*, *42*(3–4), 143–166. https://doi.org/10.1016/S0921-8890(02)00372-X

Future of Privacy Forum & Family Online Safety Institute. (2016). *Kids and the connected home: Privacy in the age of connected dolls, talking dinosaurs, and battling robots*. Retrieved from https://fpf.org/2016/12/01/kids-connected-homeprivacy-%0Aage-connected-dolls-talking-dinosaurs-battling-robots/

Holloway, D., & Green, L. (2016). The Internet of toys. *Communication Research and Practice, 2*(4), 506–519. https://doi.org/10.1080/22041451.2016.1266124

Kahn, P. H., Kanda, T., Ishiguro, H., Freier, N. G., Severson, R. L., Gill, B. T., … Shen, S. (2012). “Robovie, you’ll have to go into the closet now”: Children’s social and moral relationships with a humanoid robot. *Developmental Psychology*, *48*(2), 303–14.

https://doi.org/10.1037/a0027033

Kanda, T., Hirano, T., Eaton, D., & Ishiguro, H. (2004). Interactive robots as social partners and peer tutors for children: A field trial. *Human-Computer Interaction*, *19*(1), 61–84. https://doi.org/10.1207/s15327051hci1901&2_4

Kanngiesser, P., Itakura, S., Zhou, Y., Kanda, T., Ishiguro, H., & Hood, B. (2015). The role of social eye-gaze in children's and adults' ownership attributions to robotic agents in three cultures. *Interaction Studies*, *16*(1), 1–28. https://doi.org/10.1075/is.16.1.01kan

Krämer, N. C., Eimler, S., von der Pütten, A., & Payr, S. (2011). Theory of companions: What can theoretical models contribute to applications and understanding of human-robot interaction? *Applied Artificial Intelligence*, *25*(6), 474–502. https://doi.org/10.1080/08839514.2011.587153

Kuhn, T. S. (1970). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Lee, K. M., Peng, W., Jin, S.-A., & Yan, C. (2006). Can robots manifest personality?: An empirical test of personality recognition, social responses, and social presence in human-robot interaction. *Journal of Communication*, *56*(4), 754–772. https://doi.org/10.1111/j.1460-2466.2006.00318.x

Leite, I., Martinho, C., & Paiva, A. (2013). Social robots for long-term interaction: A survey. *International Journal of Social Robotics*, *5*(2), 291–308. https://doi.org/10.1007/s12369-013-0178-y

Li, D., Rau, P. L. P., & Li, Y. (2010). A Cross-cultural study: Effect of robot appearance and task. *International Journal of Social Robotics*, *2*(2), 175–186. https://doi.org/10.1007/s12369-010-0056-9

Lightfoot, C., Cole, M., & Cole, S. R. (2013). *The development of children* (7th ed.). New York: Worth Publishers.

Looije, R., Neerincx, M. A., Peters, J. K., & Henkemans, O. A. B. (2016). Integrating robot support functions into varied activities at returning hospital visits. *International Journal of Social Robotics*, *8*(4), 483–497. https://doi.org/10.1007/s12369-016-0365-8

Looije, R., van der Zalm, A., Neerincx, M. A., & Beun, R.-J. (2012). Help, I need some body: The effect of embodiment on playful learning. In *2012 IEEE RO-MAN: The 21st IEEE International Symposium on Robot and Human Interactive Communication* (pp. 718–724). Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/ROMAN.2012.6343836

Marsh, J. (2017). The Internet of Toys: A posthuman and multimodal analysis of connected play. *Teachers College Record*, *119*(12), 1–32. Retrieved from http://eprints.whiterose.ac.uk/113557/

Mascheroni, G., & Holloway, D. (Eds.). (2017). *The Internet of Toys: A report on media and social discourses around young children and IoToys.* DigiLitEY.

Ng, I. C. L., & Wakenshaw, S. Y. L. (2017). The Internet-of-Things: Review and research directions. *International Journal of Research in Marketing*, *34*(1), 3–21. https://doi.org/10.1016/J.IJRESMAR.2016.11.003

Pellegrini, A. D., Symons, F., & Hoch, J. (2012). *Observing children in their natural worlds: A methodological primer* (3rd ed.). New York: Taylor & Francis Group. https://doi.org/10.4324/9780203101759

Peter, J. (2017a). New communication technologies and young people: The case of social robots. In R. Kühne, S. E. Baumgartner, T. Koch, & M. Hofer (Eds.), *Youth and media. Current perspectives on media use and effects* (pp. 203–217). Baden-Baden, Germany: Nomos. https://doi.org/10.5771/9783845280455-203

Peter, J. (2017b). Social robots and the robotification of childhood. In S. Chaudron, R. Di Gioia, M. Gemo, D. Holloway, J. Marsh, G. Mascheroni, … D. Yamada-Rice (Eds.), *Kaleidoscope on the Internet of Toys: Safety, security, privacy and societal insights (EUR 28397)* (pp. 14–16). Luxembourg: Publications Office of the European Union. http://doi.org/10.2788/05383

Peter, J., & Valkenburg, P. M. (2016). Adolescents and pornography: A review of 20 years of research. *The Journal of Sex Research*, *53*(4–5), 509–531. https://doi.org/10.1080/00224499.2016.1143441

Przeworski, A., & Teune, H. (1970). *The logic of comparative social inquiry*. New York: John Wiley & Sons.

Riek, L. D. (2012). Wizard of Oz studies in HRI: A systematic review and new reporting guidelines. *Journal of Human-Robot Interaction*, *1*(1), 119–136. https://doi.org/10.5898/JHRI.1.1.Riek

Ross, A. (2016). *The industries of the future*. New York: Simon & Schuster.

Shahid, S., Krahmer, E., & Swerts, M. (2014). Child–robot interaction across cultures: How does playing a game with a social robot compare to playing a game alone or with a friend? *Computers in Human Behavior*, *40*, 86–100. https://doi.org/10.1016/j.chb.2014.07.043

Social robot. (n.d.). Retrieved February 12, 2018, from https://en.wikipedia.org/wiki/Social_robot

Spence, P. R., Westerman, D., Edwards, C., & Edwards, A. (2014). Welcoming our robot overlords: Initial expectations about interaction with a robot. *Communication Research Reports*, *31*(3), 272–280. https://doi.org/10.1080/08824096.2014.924337

Steinberg, L. (2008). *Adolescence* (8th ed.). Boston: McGraw Hill.

Thrun, S. (2004). Toward a framework for human-robot interaction. *Human-Computer Interaction*, *19*(1), 9–24. https://doi.org/10.1207/s15327051hci1901&2_2

Valkenburg, P. M., & Taylor Piotrowski, J. (2017). *Plugged in. How media attract and affect* *youth*. New Haven, CT: Yale University Press. https://doi.org/10.1080/17482798.2017.1341116

Van Bergen, W. (2016). *De robots komen eraan! Feit en fictie over de toekomst van intelligente machines [The robots are coming! Fact and fiction about the future of intelligent machines]*. Amsterdam/ Antwerp: Business Contact.

Van Oort, F., Burger, M., & Raspe, O. (2010). On the economic foundation of the urban network paradigm: Spatial integration, functional integration and economic complementarities within the Dutch Randstad. *Urban Studies*, *47*(4), 725–748. https://doi.org/10.1177/0042098009352362

Van Straten, C. L., Peter, J., & Kühne, R. (2018). Child-robot relationship formation: A narrative review of empirial research. *Manuscript Submitted for Publication*.

Wang, W.-N., Kuo, V., King, C.-T., & Chang, C.-P. (2010). Internet of Toys: An e-Pet overview and proposed innovative Social Toy Service Platform. In *2010 International Computer Symposium (ICS2010)* (pp. 264–269). Piscata, NJ: Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/COMPSYM.2010.5685507

Winfield, A. (2012). *Robotics: A very short introduction*. Oxford: Oxford University Press. https://doi.org/10.1093/actrade/9780199695980.001.0001

Zhao, S. (2006). Humanoid social robots as a medium of communication. *New Media & Society*, *8*(3), 401–419. https://doi.org/10.1177/1461444806061951